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الرسالة بعنوان

Femoral Cross Section Geometry from Archaeological Sites of Queen Alia International Airport (QAIA) &Wadi Faynan, Jordan

Yarmouk university	جامعة اليرموك
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Thesis for Master degree of physical anthropology

دراسة بعنوان

Femoral Cross Section Geometry from Archaeological Sites of Queen Alia International Airport (QAIA) &Wadi Faynan, Jordan

BIOMECHANICAL STUDY

هندسة المقطع العرضي لعظم الفخذ مِنْ الموقعينِ الأثريين: مطار الملكةِ علياء ووادي فينان (الأردن)

دراسة حيوية ميكانيكيه

للطالب: بسام محمد الحسين

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التخصص: ماجستير انثروبولوجيا العضوية

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حقل التخصص – الأنثروبولوجيا العضوية

قدمت هذه الرسالة استكمالاً لمتطلبات الحصول على درجة الماجستير في تخصص الأنثروبولوجيا العضوية في جامعة اليرموك، إربد، الأردن

وافق عليها

عبد الحليم احمد الشياب..رئيساً

أستاذ الانثروبولوجيا العضوية المشارك ، جامعة اليرموك

زياد درويش الكردي..عضواً

أستاذ الميكانيكا الحيوية ، جامعة اليرموك

محمد فواز الروسان..عضواً

أستاذ الانثروبولوجيا العضوية المساعد ، جامعة اليرموك

2013

The contents

(Dedication)

This is one of the moments that stand by the man unable to express the large feelings that beat his chest toward people who gave him both love, support so that he can live up, and achieve his dreams.

This moment in which the tongue must speak to give all thanks and appreciation:

(To my father and my mother)

All honor and proud of what you provide me since childhood and even now.

(My brothers and sisters)

Who I lived with them the details of my life with all its.

(My wife)

For you, all my love for what you bear and provided me, so I would get my goals, and for you my children.

Acknowledgment

All thanks and gratitude to my advisor Dr. Abdel Halim Alshiyab who have given me his time, effort and support, and I bear witness that this work will not be accomplished without all of that. This tremendous support help me to accomplish my work acquiring a massive research skills and knowledge. Whatever I write, this will not give him even a little bit of his help.

I the mean time, I will never forget to send my best regards and wishes to Mr. Faris B'deir who help me in accessing the sample I have used in my thesis.

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Abstract

The aim of this study is to explore the activity pattern between males and females using cross sectional properties of the femur. Biomechanics have been widely used to assess the lifestyle among bioarchaeologic populations. Cross sectional characteristics of the femur has the validity to assess the extent of physical load & thus makes us able to infer conclusions regarding the lifestyle of bioarchaeologic populations. CT-scan is useful in physical anthropology due to its ability to view cross sectional, anterioposterior, & mediolateral attributes of the bone more accurately. Due the fact that there are different activity pattern between males & females, it is expected that there will be a differences in some biomechanics attributes. Twenty-nine femurs of adults of both sexes in the site of (QAIA) and twenty femurs of adults of both genders in the site of (Wadi Faynan), total sample are forty-nine femurs, twenty-one female femurs and twenty-eight male femurs, obtained from laboratory of physical anthropology at Yarmouk University. Osteometric board used to measure the length and the midshaft of femur. CT-scan used to measure the cross sectional femoral diameter of midshaft at the cortical and medullary areas, and both of them also measured anterior-posteriorly and latro-medullary. The ellipse model method (EMM) is used to estimate the contours of the medullary and cortical areas. Analysis of variance (ANOVA) one way is used to assess the significance of the difference between males and females using the ratio of bending rigidity in the Anterioposterior (AP) plane to the bending rigidity in the Mediolateral (ML) plane. The higher the ratio I_x/I_y (AB/ML)increases resistance to external loading. The ANOVA tests show that there is a significant difference between males and females in Ix/Iy, TA, MA, CA, Ix, Iy,

CA/TA%; and all p values are < .05. Our study revealed that Loading patterns in males were more generalized and mainly exerted torsional dynamic loads rather than loading in a single plane. The total study sample has low level of mobility evidenced by low values of mobility index, which is lower than 1. Males have more level of activity pattern than females. Mobility index could be used to compare different cultural populations but it is limited when used between males & females.

Key words: CT-scan, Mobility index, Femur cross section, Biomechanics, Ellipse Model Method. Ix/Iy: mobility index,

TA :Total area , MA: medullary area , CA: cortical area , Ix: Bending rigidity in the AP plane, Iy: Bending rigidity in the ML plane.

الملخّص

تهدف هذه الدراسةِ إلى دراسة الاختلاف في النمطَ النشاطّي بين الذكورِ والإناث باستخدام الخصائصِ المقطعية لعظمة الفخذ ، ولاكتشاف العلاقةِ بين جنسٍ ونوع النشاطِ، ووَصْف أسلوبِ حياة لسكانِ bioarchaeologic في مطار الملكة علياء الدولي ووادي فينان. من خلال دراسة مقطعيةِ عظمِة الفخذ. من استخدامات علم الميكانيكا الحيوية الكشف عن أسلوبَ الحياة بين السكانِ bioarchaeologic. عبر خصائصَ مقطعيةَ مِنْ عظمِ الفخذ لَها الصلاحيةُ لتقييم مدى التحملِ الطبيعي وهكذا تَجْعلُنا قادرين على استخراج الاستنتاجات بخصوص أسلوبِ حياة سكانِ bioarchaeologic. التصوير الطبقي مفيدُ في عِلْم الانثروبولوجيا بسبب قدرتِه لرؤية مقطعيةِ متقاطعةِ ، anteriopposterior، وخواص mediolateral العظمي بدقّة أكثر. فبالحقيقة هناك أنماط نشاطيه مختلفة بين الذكورِ والإناث، ومن المتوقّعُ وجود اختلافات في بَعْض خواصِ النشاطات أليوميه وأسلوب الحياة. تم دراسة تسعة وعشرون عظمِة فخذ بالغين من كلا الجنسين من موقعِ (مطار الملكة علياء الدولي) وعشرون عظمِة فخذ بالغين من كلا الجنسين من موقعِ (وادي فينان)، العيّنة الكليّة تسعة وأربعون عظمَة فخذ، عدد عظام فخذ الإناث واحد وعشرون عظمة، وعدد عظام فخذ الذكور ثمانية وعشرون عظمة، تم الحصول عليها مِنْ مختبرِ الانثروبولوجيا العضوية في جامعةِ اليرموك. وقد تم استخدام لوحة مقياس العظم لقيَاس الطولِ وتحديد المنتصف لعظمِ الفخذ. التصوير الطبقي يُستَعملُ لقيَاس القطرِ الفخذي المقطعي لمنتصف العظم في اللحائيةِ ومناطقِ التجويف، وقياسَ العظم بشكل خلفي امامي وجانبي . طريقة البيضاوي النموذجيةُ (EMM) تُستَعملُ لتَخمين مخططات التجويف الداخلي ومناطق لحائية. تحليل التباينِ (ANOVA ONE WEY) يُستَعملُ لتَقييم أهميةِ اختلاف الأنماط المعيشية بين الذكورِ والإناث في Mediolateral Anteriopposterior. كلما زادت نسبة Ix/Iy تزيدُ مقاومةَ التحمل للعوامل الخارجيِة. من خلال اختبارات (ANOVA) تبين أنّ هناك اختلاف ظاهر بين الذكورِ والإناث في قيم Ix/Iy, TA, MA, CA, Ix, Iy, CA/TA% وكُلّ قِيَم P< ٠٥. من خلال دراستِنا تم اكتشاف النمط النشاطي عند الذكور أكثر تَعميماً وان ممارسَة النشاطات اليومية أكثر من الإناث بشكل رئيسي، كانت عيّنة الدراسةِ الكليّةِ لَها مستوى منخفضُ مِنْ قابليةِ الحركة أثبتَت بالقِيَمِ المنخفضةِ مِنْ دليلِ قابليةِ الحركة، التي هي أوطأُ مِنْ (١). الذكور عِنْدَهُمْ مستوى أكثرُ مِنْ نمطِ النشاطِ مِنْ الإناث. دليل قابليةِ الحركة يُمْكِنُ أَنْ يُستَعملُ لمُقَارَنَة بين سكانٍ مختلفين، باستطاعته تحديد أنماط الاختلاف المعيشيِة بين الذكورِ والإناث.

Chapter I

1.1 Introduction: Bioarchaeology field of study has been growing largely in the past decades. This huge increment in bioarchaeological studies is driven mainly by advances in measurement technologies enabling researchers to ascertain more valid and accurate data and results. This made the statistical inferences and generalization also more valid. Furthermore, they use bones and teeth, which are abundant in archaeological human remains (Larsen, 1997).

In addition, bioarchaeology provides a valuable tool for understanding the past characteristics of humans; their nutrition, pathology, genetic, behavior, socioeconomic status and lifestyle(Larsen et al.,1996).

Lifestyle and physical activity could be interpreted using various methods, and this will help us in gaining more insight into past human evolution and present human development. For example, demanding physical activity pattern caused a decrease in ovarian function and fecundity among living reproductively active human females (Ellison, 1993); using this information a hypothesis could be generated to compare current trends in fertility to past human populations, provided that reproductive and physical patterns are known for both populations (Ellison, 1993).

Many archaeological sites return to the Roman period in Jordan; unfortunately, there is a lack of biomechanics studies at these sites. Two of these sites are Queen Alia International Airport (QAIA) and wadi Faynan, which are Roman sites in Jordan. In bioarchaeology, such an activity can be reconstructed using special techniques including femur cross section geometry(Ruff,2000).

Traditionally, Skeletal have been widely used in determining the habitual activities by anthropologists, which help us in identifying the archeological and ethnographic qualities of these populations from the biological signatures thus, we can validate the socioeconomic and

occupational factors that affected these populations, which facilitate exploring the activity patterns (Larsen, 1997). Human activity is diverse and complicated, it involves cognitive, emotional, social, and mechanical and biophysiologic processes that interrelate to accomplish the organisms function. In this essence, physical anthropology tries to focus on those factors in the ecological system that affects the internal biophysiologic processes. In addition to that, the human bones remain the most abundant and available of all functional systems (Larsen, 1997).

Bone has mechanical and physiological functions, the physiological functions include synthesis of blood, mineral storage, growth factor storage, fat storage, detoxification and endocrine organ(Philip et al.,1989). A mechanical function of bone is to providing support and protection for the soft body organs and enabling movement. In addition, bone is a dynamic active tissue with constant modeling and remodeling processes, which allow bone to adapt to changes in the physical loadings. These processes influenced by many factors such as hormonal, genetic, environmental and physical variables. Age is also a major factor in bone modeling-remodeling processes as bone density starts to increase until it reaches a peak point and then starts to decline (Ruff,2000)

Activity pattern is a major factor in bone modeling-remodeling processes thus these processes used to assess and describe the activity pattern. This is due to the fact that as the loading demand on the bone increases, the modeling process increases bone formation therefore bone density and strength increase that makes it more resistant to fractures (Ruff,2000).

Bioarchaeological populations assessed for their activity pattern using bone biometric properties. This will enable us to describe the lifestyle of bioarchaeological populations and the differences according to gender and to compare these changes with current human populations. Of the 206 bones in human being, femur bone considered as the weight bearer and the major facilitator and component in movement (Tartora, 2003).

Therefore, it would be the most affected, accordingly making it possible for us to compare activity pattern using this bone (Wescott, 2006)

Furthermore, in contrast to humerus bone which usually exists asymmetrical, in which the dominant arm being more dense and large diameter than non-dominant one, the femur bone is normally symmetrical (Larsen, 1997). Therefore, population's daily activities to some extant are different compared to other urban people. In bioarchaeology, activity can be reconstructed using special techniques such as femur cross section and geometry (Ruff, 2000; Larsen, 1997). Skeleton's remains have been widely used in determining the habitual activities by anthropologists. This enables us in identifying the archeological and ethnographic qualities of these populations from the biological signatures, so, we can validate the socioeconomic and occupational factors had affected these populations, and facilitate exploring the activity pattern.

1.2 The femur:

Femur is the longest and strongest bone in human body; it endures weight and pressure caused by different human activities. Furthermore, it anchors the body to the ground and plays an important role in hematopoietisis. Therefore, femur remodels during human life to adapt to physical stress, which usually indicates to the lifestyle of the individual and the population; given that human in agricultural societies face more physical stressors than those in urban societies (Ruff,2000) .

This response to physical stress requires the strength that is determined by the length, the contour and the curvature of the bone. So, one of the methods have been used to identify the remodeling process is the Ellipse Model Method (EMM)(Ruff, 2000), which uses data from the cross-section of the bone to determine the activity pattern and habitual behaviors. This study tries to identify the femur cross section properties of the people of (QAIA) and Wadi Faynan in the Jordan.

Muscles play an essential role in remodeling process, the increment in tensile force applied on them triggers bone remodeling. Midshaft of the femur provide three insertions for three muscles (1) the short head biceps femoris that arise in middle shaft at femur and extended to proximal extremity of tibia and extend the hip and flex the knee,(2) the adductor brevis muscle (3) adductor longus. The latter two muscles arise from the pubis below the pubic crest and inserts along the middle of femoral shaft and they adduct the thigh at the hip joint. However, other factors, that affect the midshaft cross-section, considered including, body size, nutrition, genetics, hormonal disturbance, disease, physical activity and age-related osteoporosis (Bridges, 1991). Sexual dimorphism influences the structure of the bones in general. Some of the differences between male and female bone are apparent in length, robusticity, contour, shape and size (Thomas et al.,2005). In the femur, these differences also apply, but the total area (TA), which reflects a ratio between the medullary area

and cortical area, is equal regardless of the gender, given that they have the same activity pattern (Larsen, 1997).

Femur is the longest and strongest bone in human body. The proximal end of it articulates with the acetabulum of the hip joint, while the distal end articulates with the tibia and patella (Tartora, 2003). It consists of the following:

head: that provide strong articulation with the acetabulum (Tartora, 2003),

neck: narrow region distal to the head and connect it to the rest of the bone (Tartora, 2003),

greater trochanter and lesser trochanter : provide points for thigh and buttock muscles insertions (Tartora, 2003),

intertrochanteric line: anterior narrow line between greater and lesser trochanters (Tartora, 2003),

intertrochanteric crest: a posterior groove like projection between greater and lesser trochanters (Tartora, 2003),

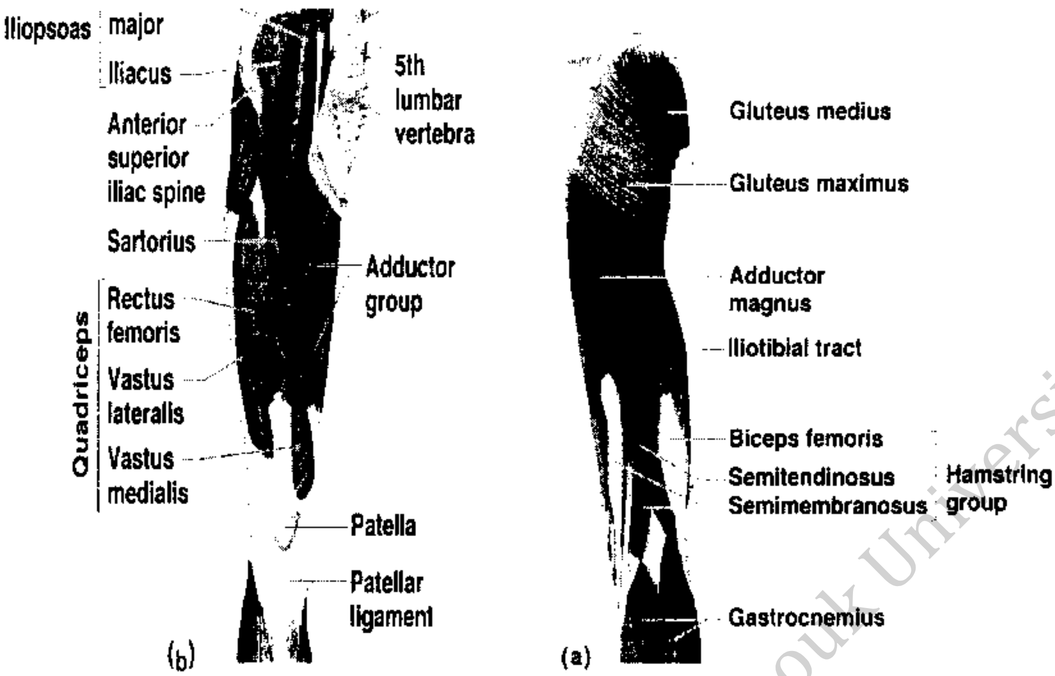
gluteal tuberosity: a vertical ridge that extend from intertrchanter crest and join with linea aspera which is also a vertical ridge line that extend just before the intercondylar fossa; both provide points for attachments for the thigh muscles (Tartora, 2003),

shaft: or the body is the largest portion of the bone (Tartora, 2003),

lateral and medical epicondyles: projections in the distal part of the femur where it expands horizontally (Tartora, 2003),

lateral and medial condyles: which articulates with tibial condyles (Tartora, 2003),

Intercondylar fossa: a depressed grove between the condyles that provide attachments for knee ligaments (Tartora, 2003). (see Appendix (B)).

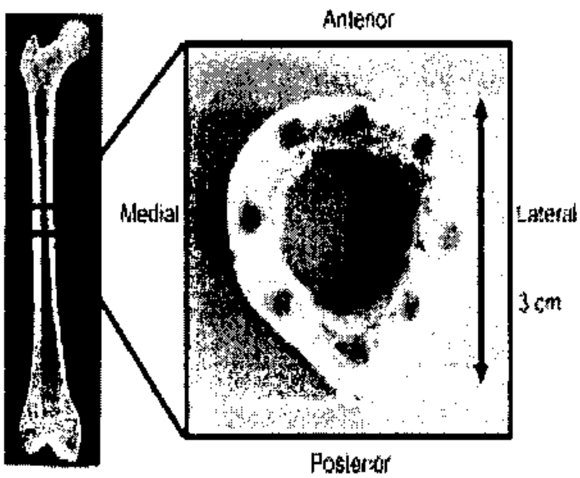


Figuer (1) Muscles attached to femur (Tartora, 2003).

1.3 Femur midshaft:

The femur midshaft has two areas: the medullary area and the cortical area, a bone tissue separates these two areas. The medullary and cortical areas expand to adapt to the environmental factors that requires more strength.(Wescott,2001) used computed tomography (CT) scan of femur to environmental factors that affected the shape of femur such as physical activity, he showed that the femur of one activity group were different in size, strength, and shape

Figure(2)



Femur midshaft

1.4 The aim of the research:

To describe the morphological characteristics of the cross section of femur & to describe the lifestyle of the bioarchaeologic population in the human remains collected from Queen Alia International Airport (QAIA) &Wadi Faynan.

To explore the relationship between activity pattern and gender among human population's remains collected from Queen Alia International Airport (QAIA) &Wadi Faynan.

1.5 Significance of the research:

Enabling us to understand better the lifestyle of people in previous ages (Roman) and help us understand better gender variations in activity pattern and human's body response to it.

This might be the first study in Jordan that utilizes CT-scan and geometric properties Ellipse Model Method (EMM) to assess activity pattern in bioarchaeological populations.

1.6 Research problem:

There may be no study in Jordan that examined the differences between male and female regarding their activity pattern and the variation in it.

This study focuses on reconstructing of the lifestyle of bioarchaeological population in Queen Alia International Airport (QAIA) &Wadi Faynan in Jordan. This is the first research in Jordan that uses CT scan for determining activity pattern evidenced by cross-section geometry of femur midshaft. Reconstructing the activity pattern of bioarchaeological population using geometrical properties adds actually to the understanding of the behavior and quality of life of the people of (QAIA) &Wadi Faynan, especially when comparing the results with others from late antiquity in the region.

1.7 Research questions:

Males and females differ in bone remodeling process; this attributed to differences in: social roles, hormonal differences, pregnancy, and lactation(Thomas ,et al 2005).

Is there a difference in activity pattern between males and females evidenced by femur cross section geometry using EMM?

Is there a difference in activity pattern between two group populations at site QAIA &Wadi Faynan evidenced by femur cross-section geometry using EMM in the same Roman period but different location?

1.8 Hypothesis:

The present study tests whether cross-sectional geometric properties of human lower limb bones can be adequately estimated using such a technique: the Ellipse Model Method (EMM) to measure contour of the total area

There is a significant difference between males and females in activity pattern evidenced by femur cross section geometry using EMM.

Chapter II

2.1 Materials & Methods:

The sample consisted of twenty-nine femurs of adults of both genders in the site of (QAIA): 13 females & 16 males; and twenty femurs of adults of both genders in the site of (Wadi Faynan): 8 females & 12 males. Total sample are forty-nine femurs, twenty-one female femurs and twenty-eight male femurs, obtained from laboratory of physical anthropology at Yarmouk University. Osteometric board used to measure the length and the midshaft of femur. CT-scan used to measure the cross sectional femoral diameter of midshaft at the cortical and medullary areas, and both of them also measured anterior-posteriorly and latro-medullary. The ellipse model method (EMM) is used to estimate the contours of the medullary and cortical areas. Analysis of variance (ANOVA) one way is used to assess the significance of the difference between males and females using the ratio of bending rigidity in the Anterioposterior (AP) plane to the bending rigidity in the Mediolateral (ML) plane. The higher the ratio I_x/I_y increases resistance to external loading.

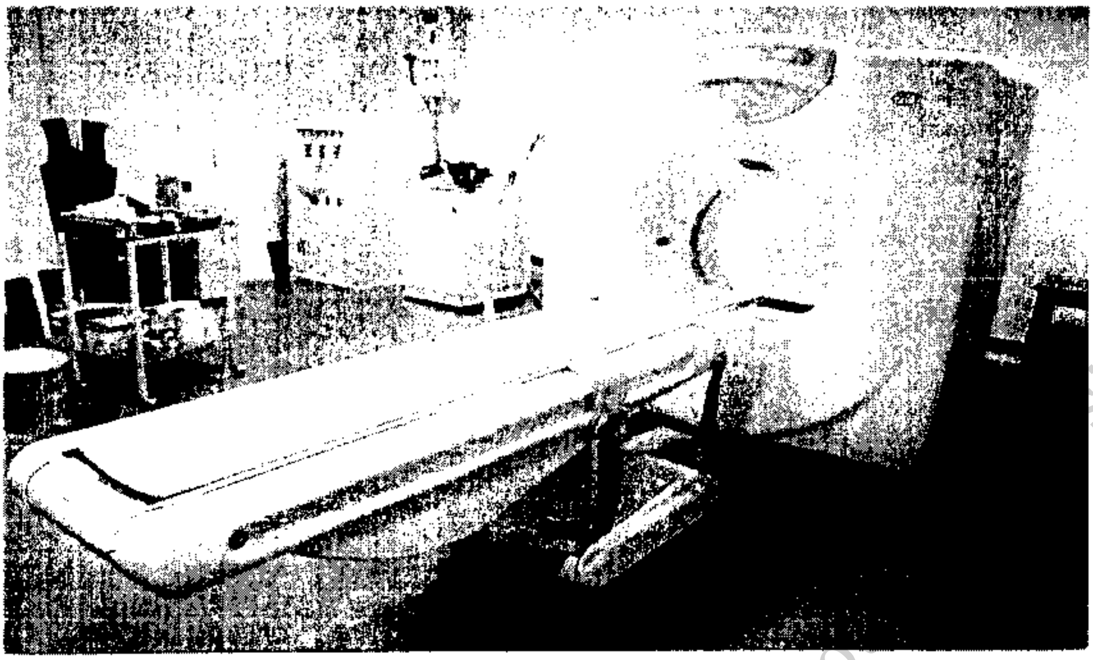
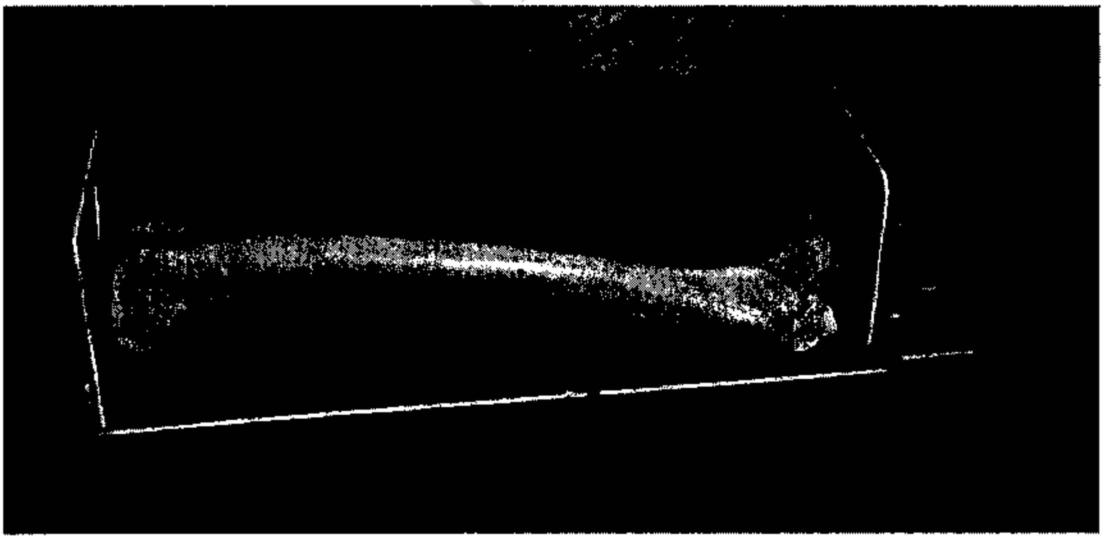


Figure (3): CT scan machine.



Figure(4) : Osteometric board.

2.2 Two Sites and samples:

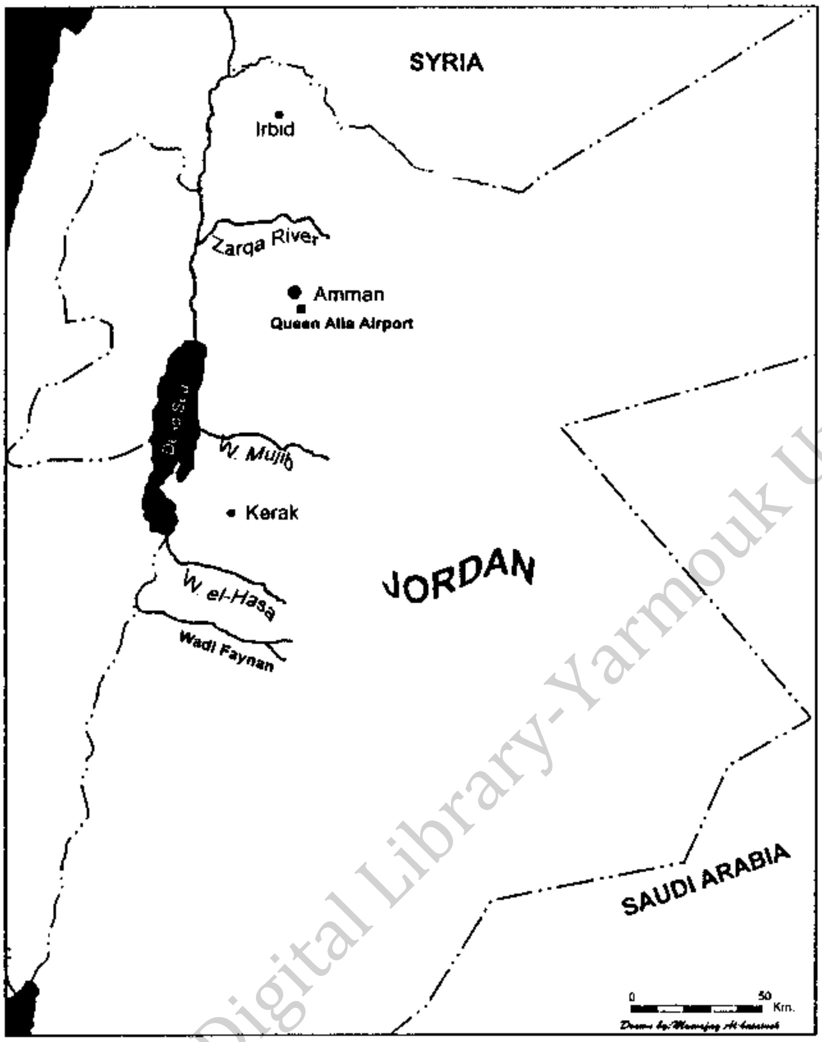
The First site of Queen Alia International Airport is located approximately 30 km south of the city of Amman. This site situated between Qulcib, Wadi al-Mansiya on the west, and Wadi al-Matabba on the east. It considered agricultural zone. The first excavation began in 1978. The second excavation started in 2000; it was also accidently

discovered during construction process of the airport. The team was under the supervision of Emsaytif Suleiman from the department of antiquity of Jordan, and excavation 52 graves, which the sample of this study obtained. Evidence of the Roman period was found in the first excavation as pottery shards and coins(Ibrahim,1987).

Ritual burial at site QAIA was individual, with each person being buried in a single grave(Ibrahim,1987).

The Second site of Wadi Faynan is located at the foothills of the Rift Valley and 300Km southwest of country's capital, Amman (EL-Najjar & Al-Shiyab, 1998). During the 1995-1996 a joint project between Yarmouk university and British institution excavated the south century of Wadi Faynan, under supervision of prof.Mahmoud El-Najjar and Dr.Abdel Halim Al-Shiyab from Yarmouk university, the uncovering of 55 human skeletons were recovered from the south cemetery site of Wadi Faynan. Evidence of late Roman and early Byzantine period the production of pottery set the stage for the extractive metallurgy of copper in the old word. Ceramic crucibles utilized in the smelting of ores and melting of metals (Bunk, 2000). Mining tools along with pottery and flint, from two distinct time's intervals, indicate that exploitation of the site had occurred during the Calcolithic and Roman period(Hauptumann ,1986).

Ritual burial at site Wadi Faynan was individual, with each person being buried in a single grave (EL-Najjar & Al-Shiyab, 1998).



Fig(5) The two archaeological sites at Jordan

Ellipse model method, AB (cortical) = anterior-posterior, ML (cortical) = medial-lateral; ab (medullary) = anterior-posterior, ml (medullary) = medial-lateral

Cross-sectional property	Equation	Mechanical interpretation
Total area (TA)	$TA = \frac{\pi}{4} * AB * ML$	
Medullary area (ML)	$ML = \frac{\pi}{4} * ab * ml$	
Cortical area (CA)	CA=TA-ML	Resistance to axial (tension or compression) loads

Second moment of area about M-L (x) axis	$I_X = \frac{\pi}{4} * a * b^3$	Bending rigidity in the AP plane
Second moment of area about A-P (y) axis	$I_Y = \frac{\pi}{4} * a^3 * b$	Bending rigidity in the ML plane
Polar second moment of area	$J = I_X + I_Y$	Torsion in polar direction
Maximum &minimum second moment of area	I_{max} & I_{min}	

Table (1): Equations for calculation of cross-sectional geometric properties for the ellipse model method (EMM). These properties including section of area and second moment of area, Total area (TA), modularly area (MA), cortical area (CA), $I_X and\ I_Y$(second moment of area), I_{max}&I_{min} (Maximum &minimum second moment of area), and J (Polar second moment of area).

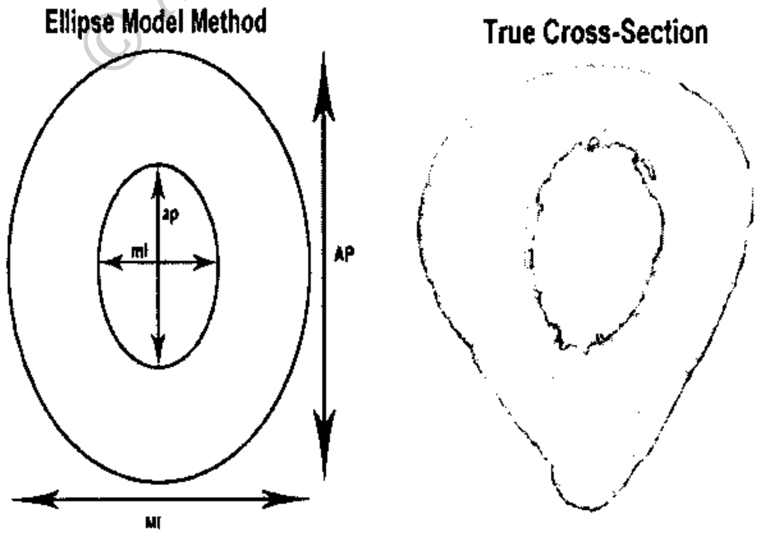


Figure (6): Ellipse model method, AB (cortical) = anterior-posterior, ML (cortical) = medial-lateral; ab (medullary) = anterior-posterior, ml (medullary) = medial-lateral (ONeil & Ruff, 2004).

Chapter III

3. Literature review:

3.1 Bone function

Bone is a vital organ for the body and provides a firm object that protects vital organs and permits the human body to stand erect. Bones also provide insertion sites for cartilages and muscles. The other function of the bone is the metabolic function that includes hematopoiesis and minerals control (Wescott, 2001).

Bones have many main functions:

3.1.1 Mechanical properties including of:

Protection: protect internal organs, such as the skull protecting the brain or the ribs protecting the heart and lungs.

Structure: bones provide the body supported.

Movement: bones, skeletal muscles, tendons, ligaments and joint function together to generate, and biomechanics deals with study of eternal and external forces causes of movement body parts.

Sound transduction: bones are important in the mechanical aspect of overshadowed hearing (Fetter & Brighton, 1999).

3.1.2 Synthetic: Blood production: the marrow, located in the medullary cavity of long bones(Philip et al., 1989) .

3.1.3 Metabolic properties including of:

Mineral storage: bones act as reserves of minerals important for the body, (calcium and phosphorus).

Growth factor storage: mineralized bone matrix stores important growth factors.

Fat storage: the yellow bone marrow acts as a storage reserve of fatty acid.

Detoxification: bone tissues can also store heavy metals and other foreign elements, removing them from the blood and reducing their effects on other tissues.

Endocrine organ: bone controls phosphate metabolism by releasing fibroblast growth factor, which acts on kidneys to reduce phosphate reabsorption (Philip et al., 1989) .

3.2 Bone structure:

The primary tissue of bone, osseous tissue, is a relatively hard and lightweight composite material, formed from calcium and phosphate in the chemical compound termed calcium hydroxyl apatite (this is the osseous tissue that gives bone rigidity). All bones consist of living and dead cells. These cells are embedded in the mineralized organic matrix that constitute the osseous tissue bone structure(Philip et al., 1989).

Bone marrow can be found in almost any bone that holds cancellous tissue. In newborn, such bones are filled exclusively with red marrow, but as the child ages it is mostly replaced by yellow, or fatty marrow. In adults, red marrow is mostly found in the bone marrow of the femur, the ribs, the vertebrae, and pelvic bones (Fetter & Brighton, 1999) (Favus, 1999).

There are four types of bone cells: osteogenic, osteoblasts, osteocytes, osteoclasts (Favus, 1999).

Osteogenic: cells are unspecialized bone cells and the only cells that undergo cell division to produce osteoblasts (Favus, 1999).

Osteoblasts: are the building cells of the bone. Osteoblasts produce collagen and other organic material in the bone matrix and they initiate bone calcification (Favus, 1999).

Osteocytes: are the mature bone cells. They are formed by entrapped osteoblasts in the matrix. Osteocytes have no secretory function; instead, they sustain the routine cellular activity of nutrients and waste exchange (Favus, 1999).

Osteoclasts: are destroyers of bone. They are formed by joined monocytes that release specialized enzymes to break the bone matrix. This is an essential process for growth, repair, and maintenance of bone tissue (Favus, 1999).

Bone strength is dependent on two factors: its hardness which depends on inorganic minerals crystallization in the matrix; and the flexibility of bone that provides tensile strength and prevents bone from torn or stretched. Collagen secreted by osteoblasts is responsible for bone flexibility (Fetter & Brighton, 1999).

Bone classification is based on the structure of the bone and on the shape of the bone. Bone structure refers to the histological characteristics of bone and hence categorized into compact bone and Trabecular.

The shape of the bone reflects the outer appearance of it and it is classified accordingly (Fetter & Brighton, 1999).

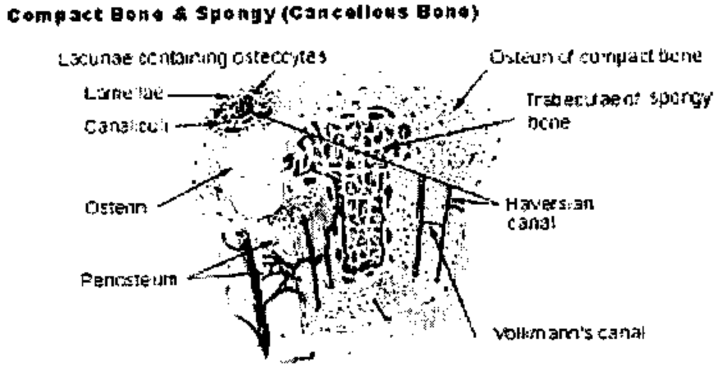


Figure (7): Long bone internal structure (Tartora, 2003).

3.3 Types according structure

Compact (cortical) bone is the hard outer layer of bones that is composed of hard bone tissue which contains few spaces between its components, and obviously reflects its protection function.

Trabecular (cancellous) bone is less hard than compact bone with more spaces in tissue compared to compact bone. Moreover, compact bone is surrounded by blood vessels, while Trabecular bone is embedded by blood vessels.

3.4 Types according shape:

There are five types of bones in the human body: long, short, flat, irregular, and sesamoid (Philip et al., 1989) .

Long bones are the bones in which the shaft, the diayphesis, characterizingly are long, in which one of the bone dimensions is much longer than other dimensions. They are mostly made of compact bone, with lesser amounts of marrow, located within the medullary cavity, and spongy bone. Most bones of the limbs, including of the fingers and toes, are long bones. The exceptions are those of the carpals, tarsals, and patella (Philip et al., 1989)

Short bones are roughly cube shaped, and have only a thin layer of compact bone surrounding a spongy interior. The bones of the carpals and ankle are short bones, as are the sesamoid bone (Philip et al., 1989).

Flat bones are thin and generally curved, with two parallel layers of compact bones sandwiching a layer of spongy bone. Most of the skull bones are flat, also as the sternum (Philip et al., 1989)

Sesamoid bones are surrounded in tendons. Since they act to hold the tendon further away from the joint, the angle of the tendon is greater than before and thus the advantage of the muscle is increased. Examples of sesamoid bones are the patella and the pisiform (Philip et al., 1989) .

Irregular bones consist of thin layers of compact bone surrounding a spongy interior; their shapes are irregular and complicated. The bones of the vertebra and hips are irregular bones (Philip et al., 1989).

3.5 Bone Formation:

The formation of bone during the fetal stage occurs by two processes: Intramembranous ossification and, Endochondral ossification (Philip et al., 1989).

Intramembranous ossification, mainly occurs during formation of the flat bones of the skull and the clavicles. In this process the bone forms directly within or on fibrous tissue, without undergoing through a cartilage stage. The steps in Intramembranous ossification are:

- Development of ossification center
- Calcification
- Formation of trabeculae
- Development of periosteum

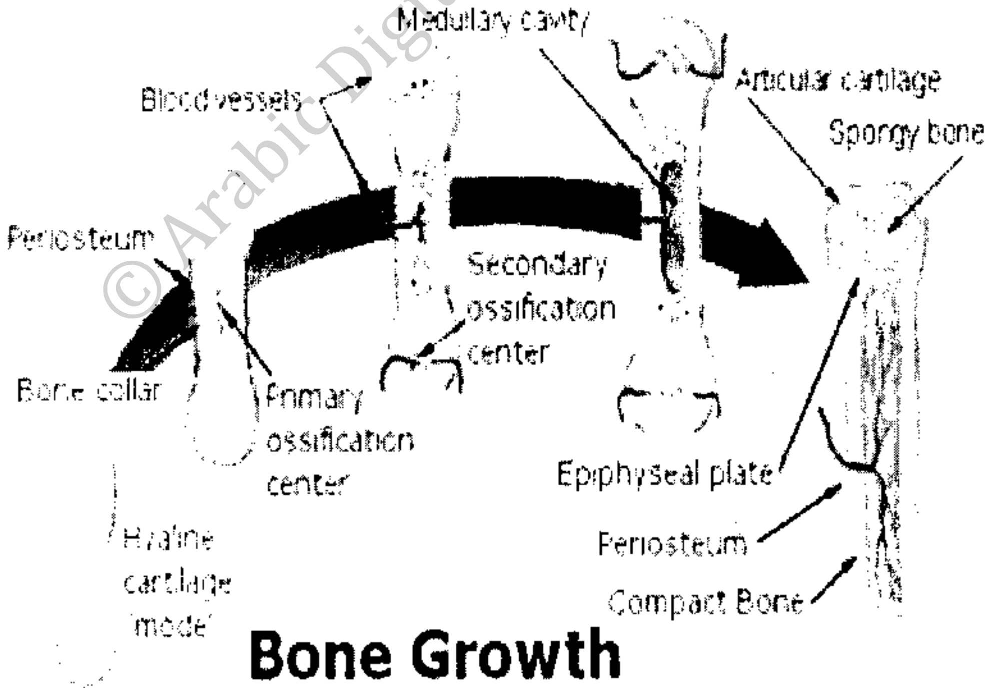


Figure (8): Bone formation (Tartora, 2003).

Endochondral ossification, on the other hand, occurs in long bones and most of the rest of the bones in the body; it involves an initial hyaline cartilage that continues to grow until modeling of the bone is completed and then gradually osteoblasts start to replace cartilage with bone. The steps in endochondral ossification are:

- Development of cartilage model
- Growth of cartilage model
- Development of the primary ossification center
- Development of the secondary ossification center
- Formation of articular cartilage and epiphyseal plate

When the individual reaches skeletal maturity (18 to 25 years of age), all of the cartilage is replaced by bone, fusing the diaphysis and both epiphyses together (epiphyseal closure) (Philip et al., 1989; Ruff, 2000).

3.6 Biomechanics of Bones:

Biomechanics is "the application of engineering principles to biological materials" (Larsen, 1997) .This provide the tools necessary to facilitate the interpretation of skeletal morphology that underwent different mechanical loadings. It takes into consideration some issues that differs from inanimate objects. These may include dynamics of the bone tissue and its ability to adapt to loadings, the differences in bone density in the whole skeleton and in different parts of the same bone, and differences in minerals composition.

The ability of the bone to respond to loadings and adjust itself to physical demand is essential for it to preserve its integrity. It has been suggested that there is a close relation between bones morphology and its functions by time, bone adjusts to the mechanical forces by a change in its size, density, shape, geometric properties. (Larsen et al., 1996).

This was formulated as a law by Julius Wolff in 1892 and this law's basic concept is the adaptation of bone to mechanical Stimuli.

Further studies was developed to attempt to explain the mechanical loadings and remodeling of bone, which are divided by their methodology into experimental approaches (Woo et al., 1981), clinical approaches (Zumwalt, 2006), studies of occupational medicine, and bioarchaeological investigations of the range of variation available in prehistory (e.g., Ruff & Hayes, 1983; Larsen & Ruff, 1991; Wescott, 2001). Bones show great sensitivity as a response to external force. Wolff (1892) as cited by Larsen (1997) concluded that every particle of mature bone is very active, that bone tissue places itself to functional demands; demonstrating bone remodeling and skeletal structural variations. He identified the patterns of skeletal remodeling under different loadings or activities.

The changes in bone due to mechanical forces are on the micro and macro level of the tissue, macro level changes are the changes in the bone as a whole structural tissue and the micro level being attributed to changes in

the composition of the bone (Zumwalt, 2006). These changes come along with other changes in the body such as metabolic changes (Wescott, 2001). For instance, stress induces the secretion of cortisol that triggers a sequence of events that may alter the composition of the bone (osteoporosis). The two processes that respond to these changes are modeling and remodeling of bone (Zumwalt, 2006).

Modeling is defined as the process responsible for modifications of internal and external bone shape and size (Ogden, 1980; (Stock & Pfeiffer, 2001)).

3.6.1 Cross sectional geometric properties of femur

Cross sectional properties of femur consist of areas, angles, diameters, & contours(Ruff, 2000). However, (Lieberman et al., 2004) argues that not all cross sectional geometric properties are useful. But they assert on cross sectional geometric properties ability to yield a useful inferences regarding pattern when used to compare bones in the same species & that J is probably the best single parameter to use for analyses of cross-sectional geometry when no experimental data on loading is present. (Nelson et al., 2004) studied the difference in geometric cross sectional properties of the femur among white and black women from Detroit and Johannesburg. the sample consisted of 237 U.S. subjects of them 86 blacks and 151 whites; and 108 South African subjects 60 blacks and 48 whites postmenopausal women. Their results showed that South African whites, U.S. whites had wider femoral necks and a greater section area in the shaft. furthermore, U.S. whites had greater cross-sectional area in both the neck and shaft. The U.S. blacks had significantly greater outer diameters, cross-sectional areas, endosteal diameters, and section area in the neck region compared with South African blacks. Their observations were consistent with greater bone strength in the black groups in both countries, and suggest that there are fewer differences between the same ethnic groups in the two countries than there are between different ethnic groups within a country.

In another study Wescott (2006) investigated the differences in femur midshaft shape, robusticity, and sexual dimorphism from external measurements between prehistoric and historic North American populations with different subsistence strategies and inferred levels of mobility. The sample was divided into six groups to test whether observed femur midshaft variables has the same patterns predicted by archaeologically and historically determined subsistence and mobility index. The study results showed that there is a significant variation in femur midshaft shape and robusticity in all populations. Results support the prediction of sexual dimorphism among highly mobile populations.

In addition,(Trinkaus & Ruff, 2012) used cross-sectional geometric properties of femoral and tibial diaphyses in the genus Homo through the Pleistocene to study loco motor robustness. They attributed the difference between the two samples to variations in pelvic and body proportions.

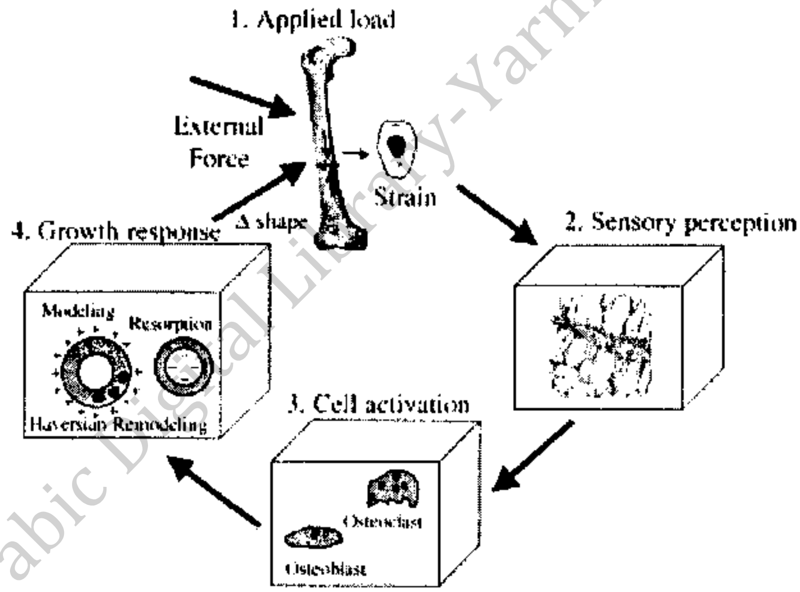
3.6.2 Microlevel responses to loadings

Modeling bone:

Modeling can be divided into two phases: resorption of existing bone by osteoclasts and formation of new bone by osteoblasts. Modeling is very active during early growth, declines with age, and terminates at maturity (Frost, 1980; Ogden, 1980). Frost (1997) reports that modeling can be stimulated among individuals as old as 30 years when their skeleton is subjected to massive amount of mechanical loading. This process reaches its peak during the high growth rate in adolescence . This is a time when nearly 100 % of the bone's surface is active (Broadhurst, 2001). Modeling strengthens bone under various kinds of mechanical loadings by increasing length, width, weight, and density, and how bone is distributed geometrically around the neutral axis (Drapeau & Streeter, 2006).

Remodeling bone:

The process of remodeling is the process by which bone reshapes itself in response to external stimuli. Response to mechanical loading contributes to a difference in bone distribution rather than bone density (Ruff, 1989; Ruff, 2001). The resistance of bone is strongest when the tensile force far from the neutral axis and centroids (Ruff, 1992) (Drapeau & Streeter, 2006). This process is followed by replacement of bone with little change in shape and occurs throughout a person's life. Osteoblasts and osteoclasts, joint together, are referred to as bone remodeling units(Ruff, 2000, Ruff, 1989),.



Figure(9): Bone response to loadings (Robling et al., 2000).

Osteoblasts stimulation:

Osteoblasts can be stimulated to increase bone mass through increased secretion of osteoid and by inhibiting the ability of osteoclasts to break down osseous tissue. The secretion of growth hormone stimulates bone building through increased secretion of osteoid by the pituitary, thyroid hormone and the sex hormones (estrogens and androgens). These

hormones also promote increased secretion of osteoprotegerin. Osteoblasts can also promote resorption of bone by Inhibiting osteoclasts activity and differentiation from progenitor cells (Philip et al., 1989).

Osteoclast inhibition:

The rate at which osteoclasts inhibited by calcitonin and osteoprotegerin is secreted by osteoblasts and inhibiting osteoclasts stimulation (Philip et al., 1989). This will prevent further destruction of bone tissue by osteoclasts. Some pathological diseases are caused by excessive osteoclastic activity such as osteoporosis, anemia, and Paget's disease.

Repeated stress, such as exercise or bone healing, results in the bone thickening at the points of maximum stress (Wolff's law). It has been hypothesized that this is a result of bone's properties, which cause bone to generate small electrical potentials under stress (Ruff, 1992).

In distinguish to modeling, this process does not typically influence length, width, density, weight, or geometric properties of bone and only 20% of bone surface is active at any time (Broadhurst, 2001).
The remodeling process is viewed as multiple steps that can be divided into six steps: activation, bone resorption, reversal, bone formation, mineralization, and quiescence (Martin & Burr, 1989).

Activity	Bone Remodeling	Bone Modeling
Local coupling	Formation and resorption are coupled	Formation and resorption are not Coupled
Timing and sequence Activity	Cyclical: A1-RS2-RV3-F4- M5-Q6; Formation always follows resorption	Formation and resorption occur continuously in separate bone surfaces, not in the same bony surface.
Extent of surface Activity	Only 20% of surfaces are active	100% of surfaces are active
Function	Skeletal maintenance and repair	Gain in skeletal mass increase in bones length, width, and changes in geometric distribution of skeletal material
1 Activation, 2 Resorption, 3 Reversal, 4 Formation, 5 Mineralization, and 6 Quiescence		

Table (2) the differences between two osteogenic processes: remodeling and modeling (After Frost, 1980; Ogden, 1980; & Broadhurst, 2001).

Factors that influence these two processes may include variation in the expression of genes, variation in diet, as well as endocrine levels and biomechanical stresses; (Wescott, 2001). Biomechanical stress includes body mass, body proportions, habitual postures, and types and levels of behavioral activities during activities (Ruff, 1992).

3.6.3 Macrolevel response to loadings

Various mechanical loads on bone can result in alterations in its external shape, as well as the bone internal distribution around its neutral axis.

Furthermore, bone density may change as a response to mechanical loading, which is expressed as mechanical stress. Mechanical stress that affect bone may be divided into bending, compression, tension, torsion, twisting, or combinations. The action of muscular attachments to the bone is the cause of these mechanical loadings (Ruff, 1992). This establish the importance of understanding the specific habitual activity pattern and its effect on body parts.

Long bones could viewed as a hollow and symmetrical cylinders. This allow us to apply mathematical models developed by engineers to evaluate the mechanical loadings on bone. But the irregularities in shape should be taken into consideration, because they may limit the application of the model (Larsen, 1997).

Bone can undergo different types of mechanical loadings. These are tension, compression, torsion, bending, shear, or combination. In reality bone experience different loads during activity. The stress on the bone reaches a point after which no more stress can be tolerated. This is determined by the safety factor of the bone, which is the ratio of bone failure strain to maximum functional strain.

3.7 Types of loading

Tension

Tension loading is the effect of two equal but opposite forces applied on an object. Consequently, bone osteons deboned and then the bone elongate and starts to tear. The tear is linear and proportionate to the pulling forces (Duda et al., 1997).

Compression

This type is the opposite of tension. It is characterized by placing the load directly on the surface of the object from its two edges. this means that forces are compressing the bone in two dimensions. This also will cause linear lines of strain; however, bone becomes shorter and wider until a certain when bone cannot endure more stress and breaks (Sumner & Andriacchi, 1996).

Torsion (Twisting)

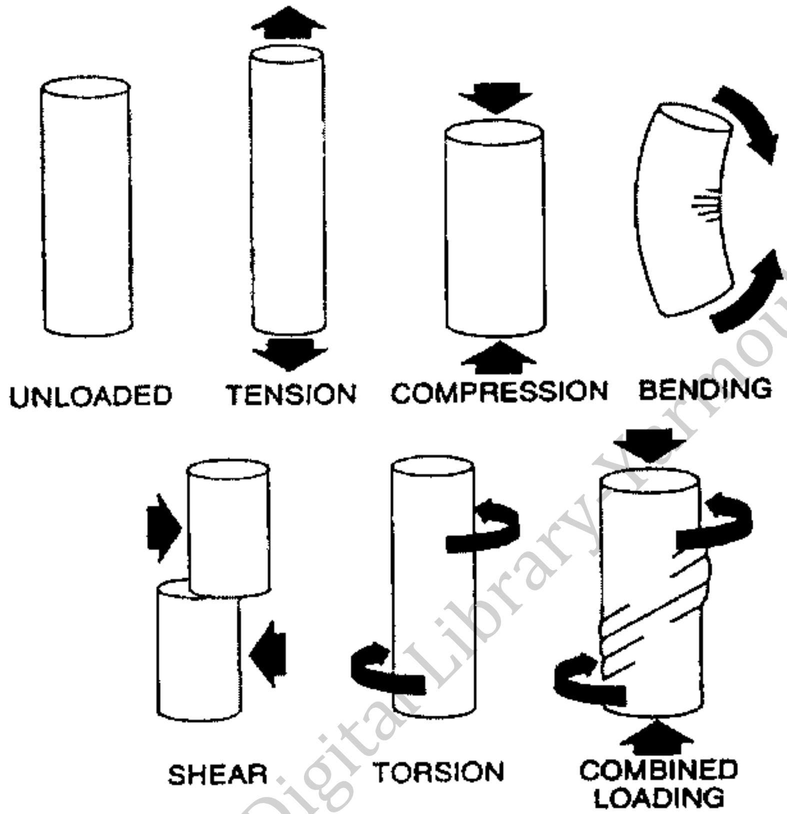
This type of mechanical loading causes twisting around the bone axis. The internal structure of bone is strained angularly, not linearly. In addition, this type may come along with tension or compression. The magnitude of loading is proportional to the distance from the bone neutral axis. This implies that long bones are more likely at risk of bending fractures (Sumner & Andriacchi, 1996).

Bending

This type the bone is subjected to external load imposed perpendicularly to its longitudinal axis. The bone should have at least one small dimension compared to the other dimensions. This type of loading is converted into compression and tension. Like torsion, the magnitude of loading is proportional to the distance from the bone neutral axis. This implies that long bones are more likely subject to increase risk of bending fractures (Sumner & Andriacchi, 1996).

Shearing

Is this type the loading the load is parallel to the cross section of the bone and internal angular changes occur. Tension and compression loads also produce shear loading (Sumner & Andriacchi, 1996).



Figure(10): Different types of loadings (Larsen, 1997).

3.8 Beam theory

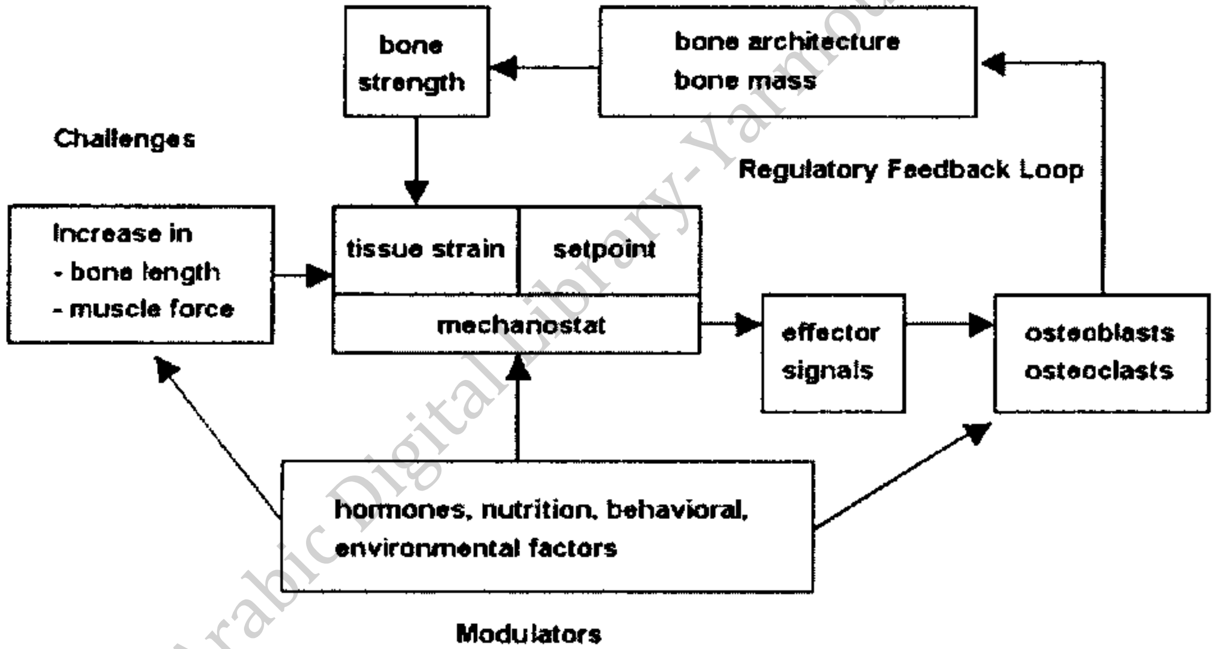
This theory of mechanics is utilized in biomechanics to view the bone as a beam curved in tow dimensions, for which the cross-sectional properties differ along bone length. This theory is used in bioarchaeology to evaluate the loadings imposed on bones by calculating cross-sectional second moments of areas. It uses the proportional relationship between the bone area and the magnitude of compression and tension forces imposed on the long axis of the bone. Only the most regular portion of the femur (i.e. the diaphysis). Methods derived from this theory apply mathematical formulae, which are used to predict the mechanical strength of hollow beams to the cross-sectional geometry of long bones and to estimate the mechanical competence of bone under various types of loading (Hodges, 2006).

3.9 Mechanostat theory

This theory developed by Harold Frost (1980,1997) states that bone undergoes homeostatic regulatory mechanism in response to mechanical stimuli. This mechanism senses changes in the mechanical demands placed on bone. Subsequently, this will alter the mass and shape of the bone to bear the new mechanical demands. Additionally, several mechanical thresholds control this process and determine whether bone mass is increased or decreased form. Frost theorized that under certain threshold of mechanical demand, bone is resorped. However, above certain threshold in which bone experience greater loadings, bone formation occurs and consequently bone mass and strength increased. This process of functional adaptation is called mechanostat (Frost, 1997). This mechanism is composed of several components, including stimulus which may be loading, sensory mechanism that are able to detect changes caused by the stimulus, and effector mechanism that made the changes needed for the bone to adapt and reach it homeostatic status.

This theory predicts that heavy weights contribute to more harder and dense bones than repetition. The disuse of bones makes the bones less harder and less dense.

Mechanostat provides a biomechanical explanation for why weight lifters have more bone than marathon runners (Frost, 1997). This explanation is based on the mechanostat theory, that the amount of load is the most essential factor in deciding bone size, density, and other morphological features, and not the rate of repetition.



Figure(11) : Functional model of bone development based on the mechanostat theory. The factors shown below represent various aspects of the central regulatory mechanism. From Rauch & Schoenau (2001).

3.10 Strain rate theory

The conclusions of mechanostat theory is partially contradicted by the results provided in studies by Alexander Robling (2000, 2001) who asserts that the period of loadings and repetition of it is the major factor in stimulating structural changes (Robling ,2001). He does not ignore the effect of the magnitude of loading, but he states that the mechano-sensitive changes return to its normal state after one day of non loading, which in turn potentiate more changes in the bone density and structure. Other studies conducted by Alexander Robling and his colleagues used experimental and simulative techniques using human and nonhuman bones, which provide more power in their findings.

Using the rat tibia four-point bending model, the right tibia of 144 adult female Sprague-Dawley rats was subjected to bending, sham bending or no loading. In the rats receiving recovery periods between loading bouts, histomorphometric measurements from the endocortical surface of the loaded and nonloaded control (left tibiae) revealed more than 100 % higher relative bone formation rates in the 8 h recovery group than in the 0 and 30 minutes recovery groups. About 8 hours of recovery was adequate to return full mechanosensitivity to the cells. Furthermore, a14 seconds of recovery resulted in significantly higher (66–190 %) relative bone formation compared to other shorter recovery periods(Robling, 2001).

Other study conducted by Robling et al. (2000) tested the impact of more frequent and shorter bending load trials on bone mass. This was done by forcing 360 bending cycles per day. These were delivered in 1,2,3,4, or 6 cycles over the three days of loadings on right tibias of 36 adult female Sprague Dawley rats. They concluded that a total of 360 bending cycles was more effective stimulus for bone formation once divided into 60 cycles in six trails and/or 90 cycles in four trials interval than when forced in one single cycle.

Burr et al. (2002) findings support the previous study's conclusion that higher rates of mechanical loadings stimulate the osteogenic response more effectively, despite short duration of loadings. They further stress the importance of the length of recovery period between the sessions of mechanical loads on osteogenic response to loading.

But these studies should be applied to human skeleton changes carefully, because of the differences in bone composition, density, and quality between humans and rats(or animals in general). A study conducted by Aerssens et al. (1998) compared bone composition, density, and quality in bone samples derived from seven vertebrates that are commonly used in bone research, these included: human, dog, pig, cow, sheep, chicken, and rat. They reported large interspecies differences in all analyses. And of these species, rat bone was most different, whereas canine bone best resembled human bone. Additionally, bone density and mechanical testing analyses were performed on long trabecular bone cores. Both analyses demonstrated also large interspecies differences. The lowest bone density and fracture stress values were found in the human sample.; porcine and canine bone best resembled human sample. The relative contribution of bone density to bone mechanical competence was largely species-dependent. They suggest to considered these differences when selecting a fitting animal model for bone research. More research is needed to confirm these results and provide tangible evidence in choosing an animal model that resemble human bones more accurately.

We can conclude from the studies above that the magnitude of loading coupled with repeated load-recovery periods are major contributors to bone modeling-remodeling processes and macrolevel bone changes.

Chapter IV

4.1 Results

A one way ANOVA was performed to identify the significance of the difference in study variables means between male and female femurs. This test was used because it is more powerful than t-test and more robust to violations to statistical assumptions (Field, 2009).

Preliminary analyses were carried to assess the data and assure that there is no violation to the assumptions of ANOVA.

Even though F-statistic is robust to violations of normality when sample sizes are equal(Glass,et al. 1972) when sample sizes are different the power of F-statistics decreases (Lunney, 1970). ANOVA assumes normality within each group, so Shapiro-Wilk test was performed to assess the normality within each group. Non of the study variables have a signficant deviation from normality using shapiro-wilk test for normality, beacause all p values were above .05. Additionally, non of z-score of kurtosis and skewness were above the 3.29 criteria which gives us more confidence in our results (Tabachnick & Fidell, 2007).

Outliers are values that vary greatly from other values and bias the mean (Field, 2009).The analysis showed that the maximal z value is equal to 3.1 for the MA. This indicates the data have no significant outliers evidence by the absence of values above or equal to the absolute value of 3.29 as suggested by (Tabachnick & Fidell, 2007).

To assess for the homogeneity of variances Leven's test was carried out. Using leven's test for homogeniety of variances test there were 3 variables that violated the assumption of homogeniety of variance. These variables are Ix, Iy, and polar second moment of area J.

The violation of homogeneity of variances lessens the power of the test, consequently we used Welch's F to compensate for the dfferences in sample sizes for the 4 variables described above (Field, 2009). Having

assured that the data are normality distributed and the homogeniety of variances were stabilized using Welch's F, the test power and validity are maintained.

Table (5) displays the ANOVA tests for each variable and means and standard deviations for each variable for both males and females. The ANOVA tests show that there is a significant difference between males and females in Ix/Iy, TA, MA, CA, Ix, Iy, CA/TA%, and J; all p values are < .05. (see Appendix (A)).

Site	TA(cm)	MA (cm)	CA (cm)	Ix	Iy	CA/TA %	Ix/Iy	J
	5.6	1.07	4.54	35.2	42.25	80.94	0.83	77.45
	3.74	0.56	3.18	18.7	16.29	85.04	1.15	34.99
	4.76	1.58	3.17	28.78	22.81	66.74	1.26	51.59
	4.22	1.47	2.76	20.69	19.26	65.25	1.07	39.95
	4.15	0.77	3.38	22.11	20.32	81.49	1.09	42.43
	4.91	0.94	3.97	29.59	29.48	80.83	1	59.07
	5.08	0.89	4.19	30.33	33.52	82.51	0.9	63.85
	4.36	0.62	3.74	26.62	21.08	85.7	1.26	47.7
	4.1	1.21	2.89	19.14	19.88	70.48	0.96	39.02
	5.78	0.55	5.23	44.59	39.94	90.43	1.12	84.53
	4.86	1.28	3.58	29.65	26.48	73.59	1.12	56.13
	4.1	0.56	3.54	21.06	20.94	84.35	1.01	42
QAIA	4.87	1.34	3.53	24.86	31.36	72.42	0.79	56.22
	4.16	0.75	3.41	19.24	23.6	82.08	0.81	42.84
	4.45	0.97	3.48	23.99	23.96	78.25	1	47.95
	5.3	1.78	3.52	30.67	32.91	66.4	0.93	63.58
	4.54	0.7	3.84	24.97	26.3	84.65	0.95	51.27
	4.98	1.83	3.15	26.22	28.38	63.29	0.92	54.6
	5.82	1.13	4.7	39.49	43.82	80.68	0.9	83.31
	5.48	1.47	4.02	31.22	40.43	73.27	0.77	71.65
Wadi Faynan	4.94	1.65	3.29	24.09	31.68	66.58	0.76	55.77

Table (3): Data collected for femur midshaft cross section of females at QAIA & Wadi Faynan.

Site	TA (cm)	MA (cm)	CA (cm)	Ix	Iy	CA/TA%	Ix/Iy	J
	5.17	2.17	3	22.7	34.64	58.08	0.66	57.34
	5.35	1.03	4.32	34.25	35.9	80.75	0.95	70.15
	4.33	1.02	3.3	20.66	24.48	76.36	0.84	45.14
	5.81	1.21	4.59	40.18	41.92	79.1	0.96	82.1
	7.61	2.88	4.73	58.76	67.94	62.18	0.86	126.7
	5.81	1.63	4.18	35.62	44.01	71.9	0.81	79.63
	7.18	1.48	5.7	66.09	59.76	79.41	1.11	125.85
	6.92	0.82	6.09	63.92	56.51	88.08	1.13	120.43
	6.99	1.37	5.62	59.17	60.64	80.38	0.98	119.81
	5.43	2.16	3.27	32.67	30.52	60.23	1.07	63.19
	6	0.95	5.05	44.67	44.8	84.21	1	89.47
	6.42	1.09	5.33	44.89	57.79	83.04	0.78	102.68
	6.31	1.31	4.99	39.2	59.88	79.17	0.65	99.08
	6.13	1.28	4.85	43.8	47.8	79.08	0.92	91.6
	5.22	0.77	4.45	32	36.02	85.25	0.89	68.02
QAIA	5.45	1.04	4.41	35.16	37.69	80.86	0.93	72.85
	6.2	1.07	5.13	47.3	47.65	82.73	0.99	94.95
	7.59	2.09	5.5	64.61	70.91	72.43	0.91	135.52
	6.26	1.27	4.99	37.78	60.58	79.72	0.62	98.36
	7.23	1.97	5.26	64.44	58.74	72.76	1.1	123.18
	5.73	1.26	4.47	35.78	44.19	78	0.81	79.97
	4.96	1.29	3.67	25.6	33.3	74.06	0.77	58.9
	6.11	0.63	5.48	39.66	55.78	89.71	0.71	95.44
	7.62	1.96	5.65	56.93	83.46	74.2	0.68	140.39
	6.62	1.78	4.84	49.15	54.5	73.1	0.9	103.65
	6.61	1.63	4.98	45.89	59.37	75.28	0.77	105.26
Wadi	6.39	1.53	4.86	42.39	56.62	76.12	0.75	99.01
Faynan	6.56	1.28	5.28	47.03	59.03	80.46	0.8	106.06

Table (4): Data collected for femur midshaft cross section of males at QAIA & Wadi Fynan.

variable	Gender	Sample size N	Mean (SD)	F	p-value
Ix/Iy	Male	28	0.87 (0.14)	44.624	.000
	Female	21	0.98 (0.15)		
TA	Male	28	6.21 (0.84)	5.731	0.021
	Female	21	4.77 (0.6)		
MA	Male	28	1.43 (0.51)	29.957	.000
	Female	21	1.1 (0.42)		
CA	Male	28	4.79 (0.77)	29.705	.000
	Female	21	3.67 (0.61)		
Ix	Male	28	43.94 (12.78)	45.4*	.000
	Female	21	27.2 (6.74)		
Iy	Male	28	50.87 (13.59)	48.849*	.000
	Female	21	28.32 (8.17)		
CA/TA %	Male	28	77.02 (7.49)	6.958	0.011
	Female	21	76.9 (8.05)		

J	Male	28	94.81 (24.98)	44.363*	.000
	Female	21	55.52 (14.33)		

Table (5): ANOVA test of study variables.

*Welch's F.

4.2 Discussion:

The purpose of this study was to assess the hypothesis that there is a significant difference between males and females activity pattern. The hypothesis was supported by the significant difference observed using ANOVA test. Our results indicated that the females in our sample had more level of activity than the males, specifically more walking as indicated by larger values of mobility index Ix/Iy. Mobility index has been used by researchers to study terrestrial mobility and compare it across bioarchaeological populations differing in their lifestyle and activity pattern (Ruff, 1987; Wescott, 2006).

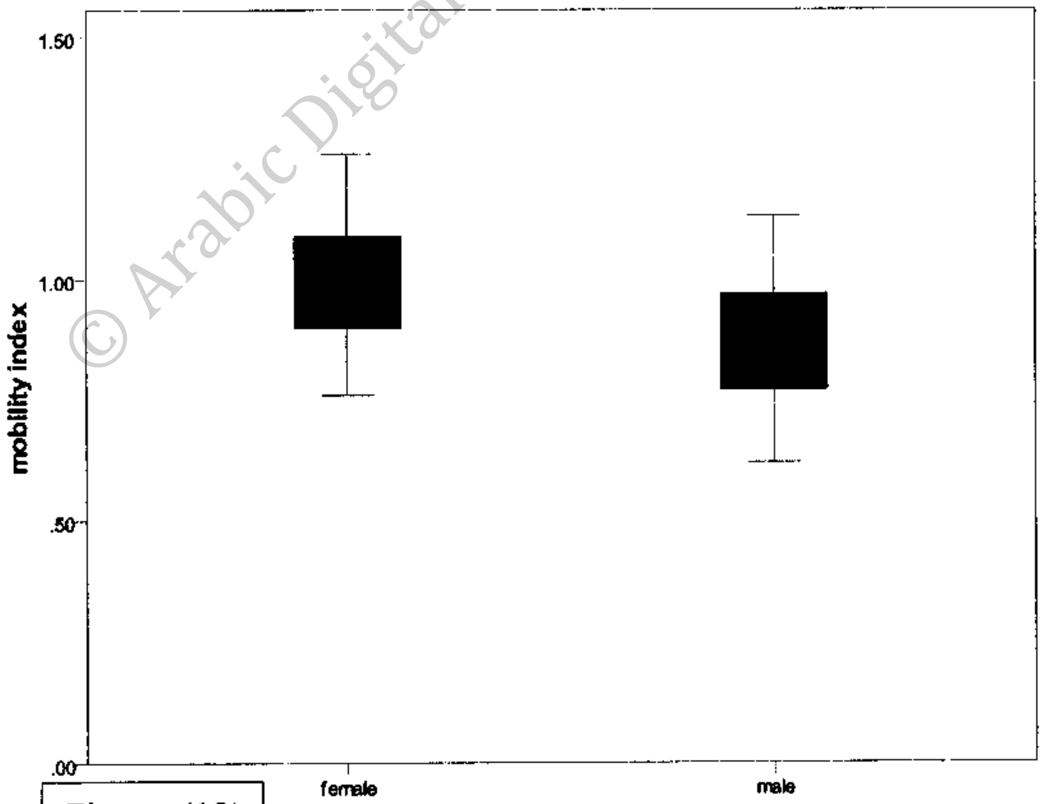


Figure: (12)

But we should be cautious in our interpretation because Ruff (1987) argued such results which show a decline in Ix/Iy for males is due to a reduction in A-P bending strength among males over lifespan, though there is no change among females. He concludes that activities among females in all types of subsistence groups require less mobility than males (Ruff, 1987). Still he did not specify the exact age at which his results could be applied. However, (Sumner & Andriacchi, 1996) states that the femoral cross sectional properties ceased to increase by the third decade. Furthermore, Wescott (2006) demonstrates that growth and development of in the mediolateral (M-L) and anterioposterior (A-P) planes in the subtrochantric femoral region is completed early in life. Prediction of sexual dimorphism could be achieved among highly mobile populations; whereas, mobility levels did not correspond with femur midshaft structure in either males or females in populations with low mobility. This is consistent with our results; as the mobility index shows that there is a low mobility level in our sample .

Our results have to be linked to the lifestyle in the historical period which the sample has been taken from; the region being agricultural based subsistence.

The significance of the results can also be attributed to division of labor between males and females. In addition, the mean values of Ix/Iy were less than 1 for both males and females, indicating low mobility for this population.

Stock & Pfeiffer (2004) compared long bone robusticity between Later Stone Age foragers of forest and fynbos biomes, taking in consideration both regional and gender differences, in upper and lower limbs. The males in both groups were found to have significantly low *Ix/Iy* ratios, this suggests that the loading patterns were more generalized and mainly exerted torsional dynamic loads on both limbs rather than loading in a single plane.

This may also be comparable to a study conducted by Ruff (1987). In this study the researcher investigated mobility index values between two subsistence groups: hunter-gatherer's and horticulturists in North America. His study indicated that the values of Ix/ Iy are greater among hunter gatherers than among horticulturists. Furthermore, hunter gathers had more elongated femoral midshaft shape in the A-P plane than horticulturists. And this confirms that the difference in lifestyle or subsistence has a significant effect on Ix/Iy.

Other study variables are significantly higher in males than females. This agrees with most studies that men undergo more loads than females (Ruff, 1987, Stock & Pfeiffer, 2004).

4.3 Conclusion: Our study revealed that Loading patterns in males were more generalized and mainly exerted torsional dynamic loads rather than loading in a single plane. The total study sample has low level of mobility evidenced by low values of mobility index, which is lower than 1. Males have more level of activity pattern than females. Mobility index could be used to compare different cultural populations but it is limited when used between males & females.

4.4 Limitations:

Differences in genetic, environmental, or biological factors may affect the study variables (Ruff, 1987; Wescott, 2006; & Pearson, 2000). This makes it difficult to make conclusions unless these confounding variables were taken into consideration. The ability to account for these covariates is not an easy task. For those variables to be entered into a statistical model, they must be measured and meet certain assumptions. In bioarcheological research this problems may arise from missing data and ambiguity and uncertainty in others. The limitations of the Ix/Iy should also be taken into consideration(Gilsanz et al.1997).

compared 30 pairs of pre-pubertal boys and girls whom were matched for age, height, and weight. They found no gender differences in the cross-sectional area of the femurs. This may lead us to conclude that the relationship is not linear with age. Our sample being ranged 20-50 and having unequal number of samples in each age group could only be generalized to adults in this age category.

Deductions from gender differences ought to be interpreted in caution due to differences in physiological processes that females undergo. For example, Laskey et al. (2010) compared mid shaft structure of post partum lactating women and followed them to post lactation period. They find that there was an increase in cross section area and cortical diameter in prelactation period compared to the period 2 weeks post partum to peak-lactation. The researchers attributed this difference to the load exerted on lower limbs during pregnancy.

Other variables needed to be accounted for are the weight, height, muscular mass, and health status and diseases of each subject the femur was taken from.

Finally, the researchers in the bioarchaeology are constrained by the size of the sample they can use for comparisons. This may affect the power of the test and make it difficult to adhere to statistical assumptions,

especially parametric tests that require the sample to be selected randomly from the population.

4.5 Recommendations

A larger sample size is needed to yield a more valid results, other studies should be conducted on different age groups and different sites; other confounding variables should be included in the analysis, so that their effects could be excluded to obtain highly reliable results.

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Appendix (A)

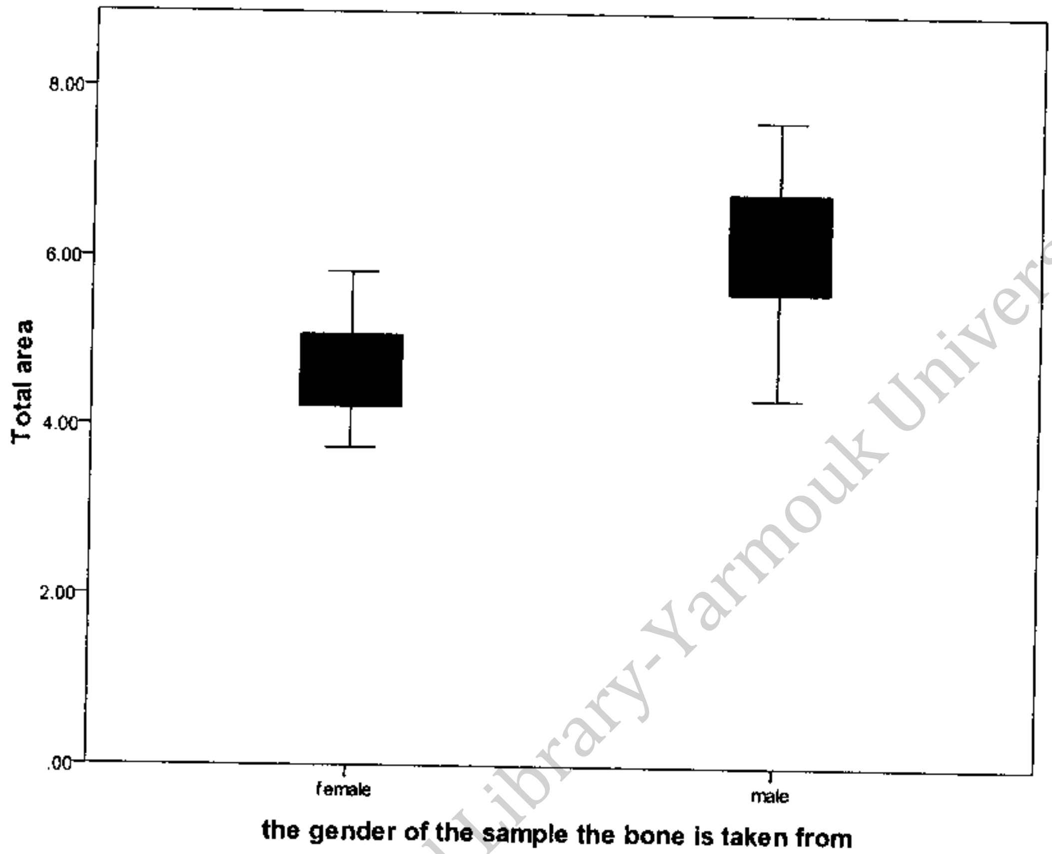
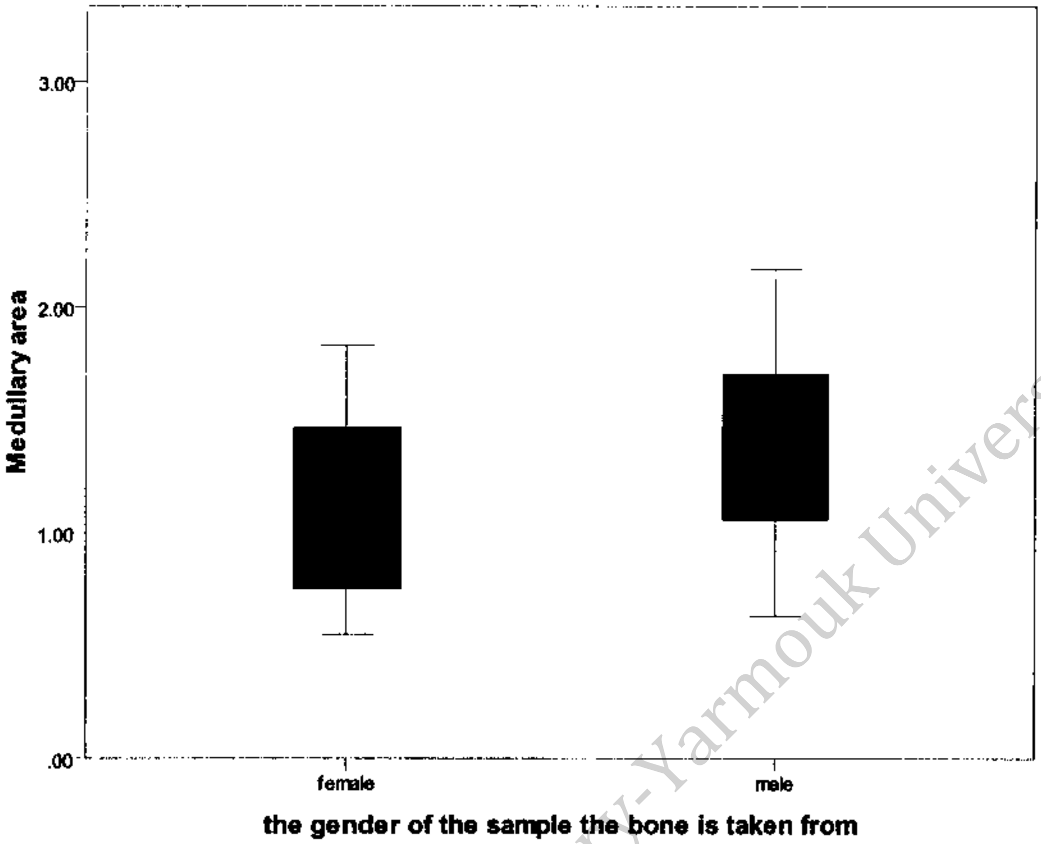
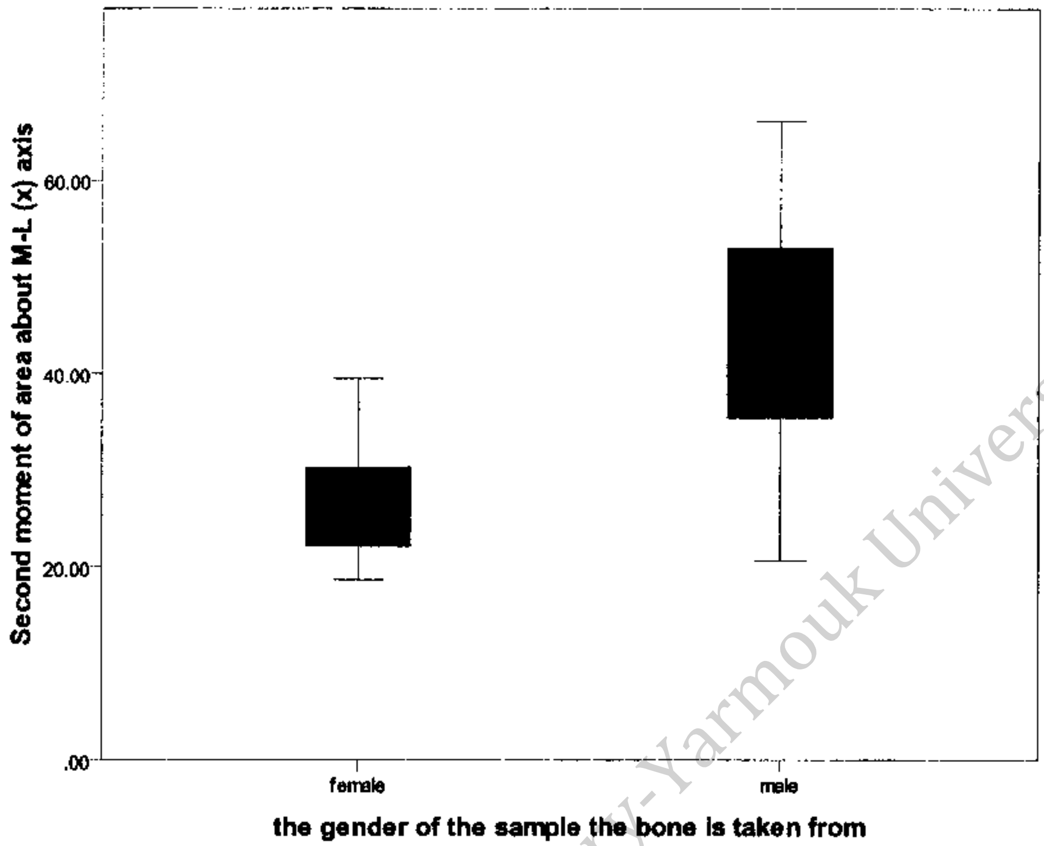


Figure (13)


3.00
2.00
1.00
.00
Medullary area
female
male
the gender of the sample the bone is taken from

Figure(14)


Second moment of area about M-L (x) axis
60.00
40.00
20.00
.00
female
male
the gender of the sample the bone is taken from

Figure(15)

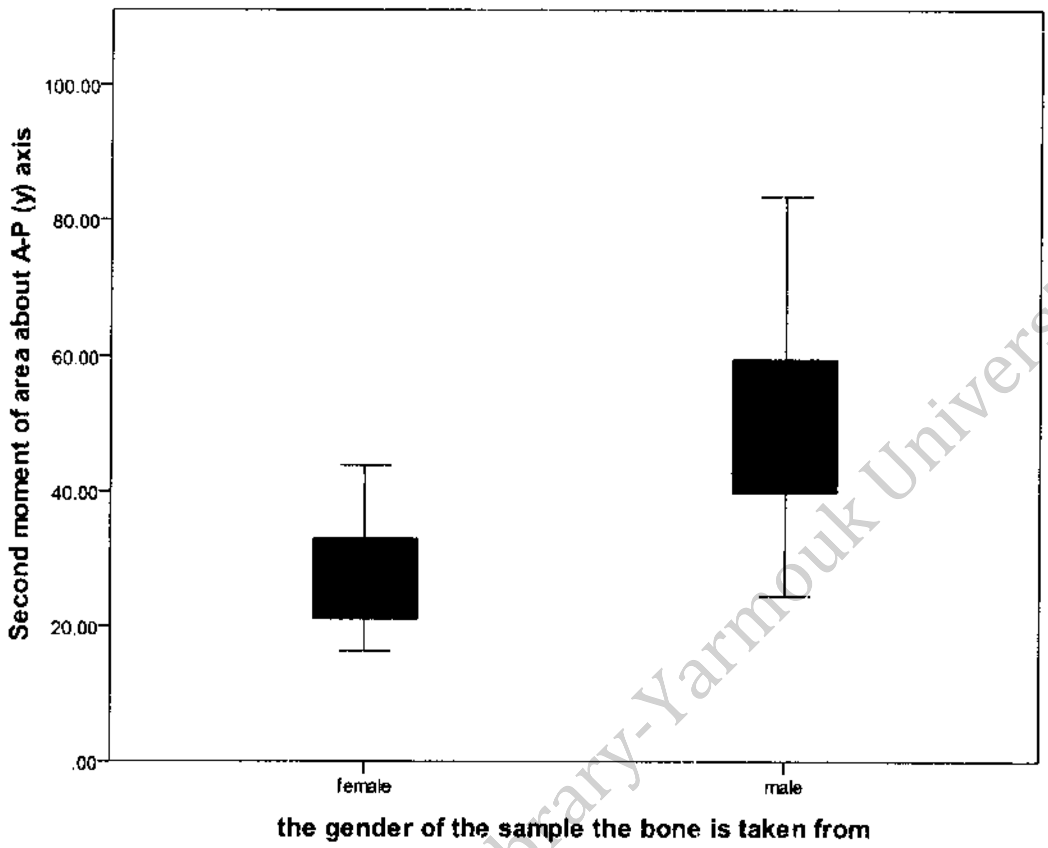

Second moment of area about A-P (y) axis
100.00
80.00
60.00
40.00
20.00
.00
female
male
the gender of the sample the bone is taken from

Figure (16)

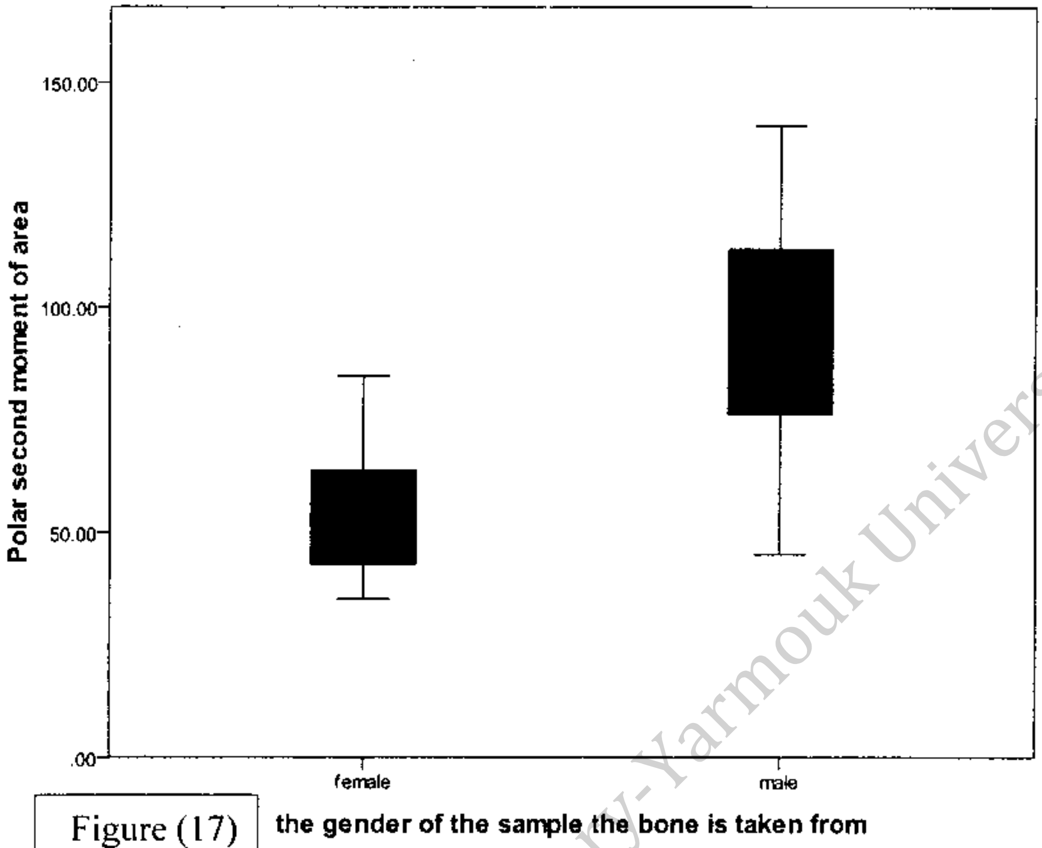

150.00
100.00
50.00
.00
Polar second moment of area
female
male
the gender of the sample the bone is taken from

Figure (17)

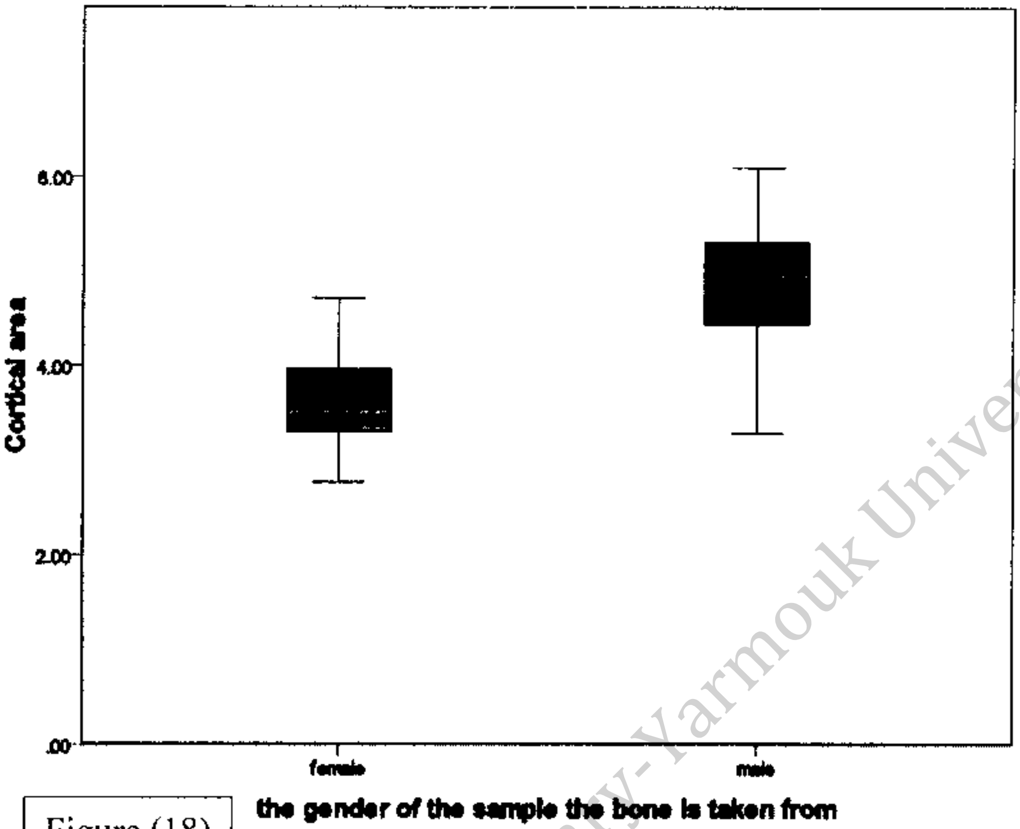

Cortical area
6.00
4.00
2.00
.00
female
male
the gender of the sample the bone is taken from

Figure (18)

Appendix (B)

Muscles attached to femur:

Muscle	Origin	Insertion	Action	
Psoas	Transverse processes & bodies of lumbar vertebrae	Lesser trochanter	Lateral rotation of thigh & flex trunk and hip at hip	
Iliacus	Iliac fossa			
Gluteus maximus	Iliac crest, sacrum, & coccyx.	Iliotibial tract of fascia lata & gluteal tuberosity of femur	Thigh extension & lateral rotation at hip	
Gluteus medius	Ilium	Greater trochanter	Abduction & medial rotation of thigh at hip	
Gluteus minimus				
Tensor fasciae lateae	Iliac crest	Tibia	Thigh abduction and flexion at hip	
Piriformis	Anterior sacrum	Greater trochanter	Thigh abduction and lateral rotation at hip	
Obturator internus	Obturator foramen, pubis, & ischium			
Obturator externus	Obturator membrane	Trochanteric fossa	Thigh abduction and lateral rotation at hip	
Superior gemilus	Ischial spine	Geater trochanter		
Inferior gemilus	Ischial tuberosity			
Quadratus femoris		Posterior of the femur	Thigh lateral rotation and hip stabilization at hip	
Adductor longus	Pubic symphysis & crest	Linea aspera of femur	Thigh adduction, flexion, & medial rotation at	Medial (adductor) compartment
Adductor brevis	Inferior ramus of			

	pubis		hip	
Adductor magnus	Inferior ramus of pubis & ischial tuberosity		Thigh adduction, flexion, & medial rotation; thigh flexion and extension at hip	
Pectineus	Superior ramus of pubis	Pectinal line of femur	Thigh flexion and adduction at hip	
Gracilis	Pubic symphisis & arc	Medial surface of tibia	Thigh adduction and medial rotation at hip	
Rectus femoris	Iliac spine	patella	Thigh flexion at hip	Anterior extensor compartment
Vastus lateralis	Greater trochanter and linea aspera			
Vastus medialis	Linea aspera			
Vastus intermedius	Anterior and lateral surfaces of femur's body			

Sartorius	Iliac spine	Medial surface of tibia	Hip flexion, abduction, & lateral rotation at hip and knee flexion	
Biceps femoris	Ischial tuberosity & linea aspera	Head of fibula & lateral condyle of tibia	Knee flexion and thigh extension at hip	Posterior flexor compartment
Semitendinosus	Ischial tuberosity	Medial surface of tibia		
semimembranosus		Medial condyle of tibia		

Appendix (C): Terminologies & definitions

Beam Theory: is a simplification of the linear theory of elasticity which provides a means of calculating the load-carrying and deflection characteristics of beams.

Bioarchaeology: is the scientific study of human skeletal remains from archaeological sites.

Biomechanics: is the application of engineering principles to biological materials.

Cancellous bone tissue: is a type of bone tissue that is less hard than compact bone with more spaces. Trabecular bone is embedded by blood vessels.

Centroids: in geometry centroids represent the intersection of two planes.

Compact bone tissue: is a type of bone tissue that is more hard than cancellous bone with less spaces in tissue. Compact bone is surrounded by blood vessels.

CT-Scan : is a process which uses X-ray equipment to produce three-dimensional representations of components both externally and internally.

Endochondral Ossification: is occurs in long bones and most of the rest of the bones in the body; it involves an initial hyaline cartilage that continues to grow until modeling of the bone is completed and then gradually osteoblasts start to replace cartilage with bone.

Hematopoietisis: is new blood cells are produced daily in order to maintain steady state levels in the peripheral circulation.

Intramembranous Ossification: is one of the two essential processes during fetal development of the mammalian skeletal system by which bone tissue is created.

Loadings: is a quantity that can be processed or transported at one time; the system broke down under excessive loads.

Maximum &Minimum Second Moment of Area: is Principal second moments of the area. Consider two sets of reference axes x-y.

Mechanostat Theory: is mechanism senses changes in the mechanical demands placed on bone. Subsequently, this will alter the mass and shape of the bone to bear the new mechanical demands.

Modeling: is divided two phases: resorption of existing bone by osteoclasts and formation of new bone by osteoblasts. Modeling is very

active during early growth, declines with age, and terminates at maturity reports that modeling can be stimulated among individuals as old as 30 years when their skeleton is subjected to massive amount of mechanical loading.

Polar Second Moment Of Area: is measures the ability for a cross-section to resist torsion and combined loads.

Remodeling: is the process bone reshapes itself in response to external stimuli. Response to mechanical loading contributes to a difference in bone distribution rather than bone density, The resistance of bone is strongest when the tensile force far from the neutral axis and centroids.

Second Moment Of Area About A-P (Y) Axis: Bending rigidity in the ML plane.

Second Moment Of Area About M-L (X) Axis: Bending rigidity in the AP plane.

Strain Rate Theory: is the major factor in stimulating structural changes a daily mechanical stimulus into a discrete loading bout optimizes the osteogenic response to loading.